Quarterly Report
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I. Near-term Objectives

Apply extensively the retrieval algorithm, developed by Nakajima and King for determining the optical thickness and effective particle radius of clouds, as well as cloud thermodynamic phase, to recently calibrated and geolocated field campaign data gathered by the MAS (MODIS Airborne Simulator). This program has thus far been applied to two channels of the MAS (0.665 and 2.142 µm), but will in the future be extended to multiple wavelengths appropriate for MODIS. A reduction of angular information, which was stored in the codes and required by the retrieval algorithm, should be sought in order to increase the capacity of the algorithm for processing additional multi-spectral information, such as the 3.75 µm channel.

II. Task Progress

a. MODIS-related Instrumental Research

The MAS data system is in the process of being upgraded to record the full complement of 50 spectral channels. The biggest issue now, according to Jeff Myers at Ames Research Center, is getting the analog-to-digital (A/D) converter boards fabricated. This will be done by Berkeley Camera Engineering and delivered around May 16. Thus, it leaves only two weeks to assemble and test the system, then chamber test and thoroughly calibrate the sensor prior to the June 1 MAST (Monterey Area Ship Tracks) deployment. However, the replacement of the port 2 and 3 dewars can be accomplished without holding up the schedule. It is possible to choose an 11 channel setup during MAST, as we have done in the past, but use 10-bit digitization on the 3.7, 8.5, 11 and 12 µm channels. The reflected solar radiation component of the 3.7 µm channel contains important information for the ship track study. Dave Augustine is close to finish the MAS Quicklook data display software. This allows the user to view the raw MAS data in either single channel, three channel simultaneous or RGB composite modes. Other options are an interactive stretch of the color tables (both upper and lower boundaries), tape manipulation (skip files, tape rewind, and position to selected scan) and custom color tables.

In addition to the new 50-channel system, Liam Gummy and Pat Grant recommended that the INS time code come directly from the GPS navigation system. However, the MAS clock time will also still be recorded. The RS-232 serial navigation data stream will be stored as-is in the MAS scan line blocks (32768 bytes/block, one scan line per two blocks) - none of the navigation data will be unpacked. The new navigation data stream will be entirely ASCII, and thus should be easy to decode. Approximately 500 bytes will be required. The video data will be stored as 2 12-bit words every 3 bytes. This will require some bit-shifting / masking to unpack, but should pose no problems.

Tom Arnold and John Cooper recently worked on MAS calibration, with both the Goddard 48-inch hemisphere and the new Ames 20-inch hemisphere (both with and without the mirror). Some problems with the Ames 20-inch hemisphere were observed, such as the order in which the lamps were turned off (which affects sphere uniformity) and hemisphere loading errors as a function of the distance from the source to the MAS. Initial results of the comparison of the 20-inch hemisphere data using the 45° mirror vs. looking directly into the hemisphere, appear consistent with the independent calibration of the mirror.

Nita Walsh and Max Strange have completed the installation and adjustment of the CAR (Cloud Absorption Radiometer) for the MAST deployment. This includes a newly selected UV-B channel in the ozone absorption band at 0.3 µm. The 13 channels of the CAR that we have selected for MAST are 0.47, 0.67, 0.30, 0.87, 1.03, 1.27, 1.22, 1.55, 1.64, 1.72, 2.10, 2.20, and 2.30 µm. Calibration of the CAR using both the six-foot sphere and the 48-inch hemisphere was performed by Tom Arnold and Nita Walsh. Preliminary results show that the calibration was successful, but considerable processing is required to get final calibration coefficients.

b. MODIS-related Data Processing and Algorithm Study

The revision of the MODIS Algorithm Theoretical Basis Document (ATBD) was completed by Michael King, Si-Chee Tsay and Steven Platnick and delivered to the EOS Pproject Science Office on time. The title of this ATBD is the "Theoretical Basis of Cloud Retrieval Algorithms for MODIS: Cloud Cover, Thermodynamic Phase, Optical Thickness and Effective Particle Radius." The initial MODIS β-version software (cloud retrieval algorithms) also has been delivered by Menghua Wang to SDST. This package includes eight lookup tables (4 for the reflection functions, 3 for the flux parameters, and 1 for asymptotic parameters) and one cloud retrieval code.

The revised ATBD is largely based on the work of Nakajima and King (1990), in which asymptotic theory is the core of the algorithm. This ATBD has been enriched by Steve Platnick's analysis of error sources in the retrieval of cloud properties. Table 1 summarized errors in retrieving effective radius for each of the MODIS near-infrared channels, as well as the AVHRR 3.75 µm channel. It is shown that errors introduced by the ways of spectral averaging (<R>) and the shift of bandwidth (BW) are relatively minor. The most significant errors arise from uncertainty in the refractive indices of water used and the absolute accuracy of sensor, due to instrument calibration or effect of the atmospheric path. Sources of error in retrievals of optical thickness (τ_c) due to uncertainties in calculation of the visible channel reflectance were also analyzed by Steven

Platnick. In general, results show that errors in surface reflectance are probably only of minor concern compared to those from the absolute accuracy of the sensor. Simple analytic approximations to retrieved errors in τ_c were also developed for these cases.

TABLE 1. Summary of approximate maximum error in retrieving effective radius for MAS near-infrared channels and AVHRR channel 3 (3.7 µm). Calculated for $\mu = 0.95$, μ_0 variable, and r_e from 5-20 µm. See text for details.

Band	$<R^{\lambda}>$ *vs* $R^{<Mie>}$	$+\lambda_c$ shift (+13% of BW)	$-\lambda_c$ shift (–13% of BW)		Errors due to sensor intensity or reflectance error				r_e (I&P) *vs* r_e (P&W) *
				τ_c	±1%	±2%	±5%	±10%	
MAS 10 (1.62 µm)	+0.09	–0.10	+0.10	50	{ EQ \o(–,+) }0.7	{ EQ \o(–,+) }1.3	{ EQ \o(–,+) }2.7	+6 / –4.5	0.119
	–0.05	–0.55	+0.55	5	{ EQ \o(–,+) }0.7	{ EQ \o(–,+) }1.3	+4 / –3	+9 / –6	0.125
MAS 20 (2.14 µm)	+0.10	–0.15	+0.15	50	{ EQ \o(–,+) }0.3	{ EQ \o(–,+) }0.6	{ EQ \o(–,+) }1.4	{ EQ \o(–,+) }0.3	0.160
	–0.30	–0.50	+0.50	5	{ EQ \o(–,+) }0.4	{ EQ \o(–,+) }0.7	{ EQ \o(–,+) }2.0	+4.5 / –3.5	0.217
MAS 31 (3.73 µm)	+0.09	–0.30	+0.30	50	{ EQ \o(–,+) }0.2	{ EQ \o(–,+) }0.3	{ EQ \o(–,+) }0.7	+1.7 / –1.4	0.256
	–0.05	–0.70	+0.70	5	{ EQ \o(–,+) }0.15	{ EQ \o(–,+) }0.2	{ EQ \o(–,+) }0.6	{ EQ \o(–,+) }1.2	0.275
				1	{ EQ \o(–,+) }0.2	{ EQ \o(–,+) }0.6	{ EQ \o(–,+) }1.4	{ EQ \o(–,+) }2.5	
AVHRR (3.75 µm)	+0.45	–0.30	+0.50	50	Same as for MAS 31				0.302
	–0.10	–0.70	+1.20	5 1					0.375

* I&P denotes Irvine and Pollack (1968) and P&W denotes Palmer and Williams (1974). These computations apply to the case when $\tau_c = 50$ and $r_e = 10$ and 20 µm.

To confirm that this cloud retrieval code returns correct values, Nakajima and King (1990) performed fundamental tests by synthesizing reflection function data from pre-computed lookup tables at identical gridded points. In addition to the analyses of MCR data, Si-Chee Tsay also modified this code to analyze some MAS data from ASTEX. For the purpose of further testing the statistical package of this retrieval code, Menghua Wang created a pseudo data set directly from the lookup tables. These pseudo data (angular distribution of reflection functions for a homogeneous cloud) were purposely chosen to be away from the gridded mesh consisting of 4 scaled optical thicknesses (0.5, 0.7, 0.9, and 1.1), 7 sun angles (5°, 15°, 25°, 35°, 45°, 55° and 65°), 5 viewing angles (5°, 15°, 25°, 35° and 45°), and 10 azimuth angles (5°, 18°, 38°, 55°, 75°, 95°, 125°, 135°, 148° and 175°) at an effective radius of 5.657 μm. An identical interpolation scheme, used in the retrieval code, was applied to create a total of 1400 pseudo pixels at wavelengths of 0.754, 1.645, and 2.16 μm from the lookup tables. After the test, a couple of minor bugs in this customized statistical code were identified and temporarily fixed by Menghua Wang for delivery to SDST. Permanent fix of these bugs will be done in the process of standardizing this code.

Two of the MAS calibration reports, for the 1991 FIRE-II Cirrus and 1992 ASTEX field experiments, were published as NASA Technical Memoranda by Tom Arnold, Michael Fitzgerald, Pat Grant and Michael King. Arnold also nearly completed the SCAR-A report. The calibrated and geolocated MAS data containing thin cirrus clouds over the Gulf of Mexico, together with CALS and HIS data, were analyzed by Liam Gumley. An index parameter derived from the MAS nadir reflection functions at 0.68 and 1.62 microns was developed which appeared to serve as a better indicator of thin cirrus clouds than either individual reflection function. Results in a paper entitled “Multi-sensor remote observations of thin cirrus clouds during FIRE Cirrus II” were presented by Liam Gumley at the 8th AMS Conference on Atmospheric Radiation, Nashville TN. Brightness temperature differences from the 8.8, 11, and 12 micron channels were also shown to illustrate the sensitivity of these channels to thin cirrus clouds.

RGB composite images from MAS and the Landsat Thematic Mapper (TM) of flooding near St. Louis were prepared by Liam Gumley for use in the MODIS brochure. This involved “box-averaging” the MAS and TM to 300, 540, and 1020 m pixel sizes to indicate the resolution available from MODIS. In addition, the flooding in the US Midwest during the summer of 1993 was also studiedy by using MAS data acquired on 29 July 1993 and a Landsat-5 TM cloud-free scene acquired over the St. Louis area on 14 April 1984.

In order to quantify the area covered by water, it was necessary to develop a means of separating water from land surface pixels. This was done by applying a threshold to the normalized digital count histograms of both the MAS 0.94 μm and TM 1.65 μm images. After careful examinations, the threshold for each image was set at the mean – 4 times the standard deviation. Pixel values less than this threshold were identified as water, while pixel values greater than this threshold were identified as land. It was then possible to estimate the fraction of water-covered pixels in each image by dividing the number of water pixels by the total number of pixels in the image. For the MAS image, the fraction of water pixels was about 23.9%, while for the TM image the fraction of water pixels was about 8.5% of the total number of pixels. Thus an estimate of the fraction of flooded pixels in the MAS image can be gained from the difference in the water/land mask fractions, indicating that about 15.4% of the MAS image is covered by ‘unusual’ flood waters. A first draft entitled “Remote Sensing of Flooding in the US Upper Midwest During the Summer of 1993” was completed by Liam Gumley for submittal to the Bulletin of the American Meteorological Society.

Tom Arnold has worked on the intercomparison between Landsat TM and MAS data for the 3 April 1993 case of CEPEX. So far results are showing significant differences in the 0.66 and 1.64 µm channels in both the slope and offset of the intercomparison. Some of the scatter in the data are believed to be due to the lack of uniformity in the cloud scene. More careful study is needed to establish a way to calibrate the MAS data obtained during CEPEX.

Ward Meyer and Si-Chee Tsay continue to work on the surface bidirectional reflectance in which data were obtained by CAR for SCAR-A flights 1611 and 1612 (28 July 1993). These bidirectional reflectance polar plots were produced for a variety of cases for flight 1612, above haze, and for flight 1611 both in haze and above haze. Many interesting effects were observed, which required additional analysis. The corresponding transmittance and reflectance data through the haze layer were calculated for the 0.47, 0.67 and 0.87 µm channels which will be used to deduce the haze properties.

c. MAST experiment preparation

The main objective of the MAST experiment is to study the physical processes by which ship tracks are formed. More fundamentally, it is to understand how anthropogenic aerosols modify the reflectivity of existing clouds (indirect effect), and thus the earth’s radiation balance. The MAST will consist of various NOAA, DMSP and GOES satellites; the NASA ER-2 aircraft carrying the MAS, CALS (Cloud and Aerosol Lidar System) and RAMS (Radiation Measurement System); the University of Washington’s C-131A and the United Kingdom’s MRF C-130 research aircraft carrying a wide variety of instrumentation to measure atmospheric dynamics, thermodynamics, microphysics, chemistry and radiation; and the Naval Research Laboratory Airship. In addition, two conventional-powered and one nuclear-powered US Navy Ships will participate in the MAST campaign to serve as controlled aerosol sources.

The importance of MAST to MODIS is that ship tracks, which exist on a small scale (minimal meteorological effects), provide a useful laboratory for the study of cloud microphysical changes as well as provide tests of instrumentation and validations of our cloud retrieval algorithm. Michael King and Si-Chee Tsay are actively involved in the science planning of MAST.

d. MODIS-related Services

1. Meetings

1. Michael D. King attended the AMS Annual Meeting in Nashville, TN on 23-28 January 1994 and presented an invited paper "The application of EOS to studies of atmospheric radiation and climate";

2. Si-Chee Tsay attended the 8th Conference on Atmospheric Radiation, AMS Annual Meeting at Nashville, TN on 23-28 January 1994 and presented two papers entitled "A Fourier-Riccati approach to radiative transfer. Part II: Computations of spectral reflectance and heating rates in cirrus-like clouds" (co-author with P. M. Gabriel, M. D. King and G. L. Stephens) and "Remote sensing and retrieval of surface bidirectional reflectance" (co-author with M. D. King);

3. Liam Gumley attended the 8th Conference on Atmospheric Radiation, AMS Annual Meeting at Nashville, TN on 23-28 January 1994 and presented a paper entitled "Multi-sensor remote observations of thin cirrus clouds during FIRE Cirrus II" (co-author with M. D. King and S. C. Tsay);

4. Steven Platnick attend the MODIS cloud mask meeting, held on 28 February-1 March at the University of Wisconsin, Madison, WI, to discuss possible algorithms for cloud masking the MODIS data and to organize the writing of the ATBD;

5. Michael King attended (and co-chaired) the Investigators Working Group (IWG) meeting in San Antonio, TX, on 11-13 January, during which made three presentations: (i) "Project Science Office Update", (ii) "EOS Validation Plan," and (iii) "Remote Sensing of Cloud and Surface Properties from Aircraft."

2. Seminar

1. Steven Platnick gave a seminar on "Cloud parameter retrievals and error analysis" to the Radiation and Climate Branch on 16 February.

III. Anticipated Activities During the Next Quarter

a. complete the work of documentation, standardization, refinement, and integration of our cloud retrieval codes to SDST;

b. complete data analyses of FIRE-II Cirrus observations gathered by the MAS, CLS, and HIS, as well as theoretical studies, and prepare manuscripts for *J. Atmos. Sci.* special issue due in June 1994;

c. apply extensively the MODIS cloud retrieval algorithm through all calibrated and geolocated ASTEX data gathered by the MAS, and prepare manuscripts for *J. Atmos. Sci.* special issue due in June 1994;

d. compare retrieved cloud parameters from the 3.75 µm channel with those obtained from the usual 0.665 and 2.142 µm channels, and look into the spectral signature of vertical profile in effective particle radius;

e. continue the effort of refining our cloud retrieval algorithm and re-examine more carefully the retrieval of cloud optical and microphysical properties by using data gathered from MAS and in situ data from Gerber's PVM probe;

f. complete the development of a quick-look system for 50-channel MAS in the field and develop methods to conduct calibrations of MAS near-IR absorption channels;

g. participate in the Monterey Area Ship Track (MAST) experiment, taking place June 1-30 from Monterey, CA;

h. continue to analyze the surface bidirectional reflectance measurements obtained during the Kuwait Oil Fire, LEADEX, ASTEX and SCAR-A experiments;

i. continue to analyze data sets obtained from the TOGA/COARE and CEPEX field campaigns and compare with co-located Landsat data.

IV. Problems/Corrective Actions

No problems that we are aware of at this time.

V. Publications

1. Arnold, G. T., M. Fitzgerald, P. S. Grant and M. D. King, 1994: *MODIS airborne simulator visible and near-infrared calibration: 1992 ASTEX field experiment*. NASA Technical Memorandum 104599, 19 pp.

2. Arnold, G. T., M. Fitzgerald, P. S. Grant and M. D. King, 1994: *MODIS airborne simulator visible and near-infrared calibration: 1991 FIRE-Cirrus field experiment*. NASA Technical Memorandum 104600, 23 pp.

3. King, M. D., S. C. Tsay and S. E. Platnick, 1994: In situ observations of the indirect effects of aerosol on clouds. *Dahlem Workshop on Aerosol Forcing of Climate*, R. J. Charlson and J. E. Heintzenberg, Eds., John Wiley and Sons (submitted).

4. King, M. D., S. C. Tsay and S. E. Platnick, 1994: Theoretical basis of cloud retrieval algorithms for MODIS: Cloud cover, thermodynamic phase, optical thickness and effective particle radius. MODIS Science Team, 52 pp.